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A QuadCopter Posture Stabilization Control using Noise Attenuated Sensor Fusion and Modified PID Control

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Abstract. In this paper, we propose a advanced attitude PID controller and sensor fusion method robust to the vibration of the quadcopter unmanned air vehicle using four BLDC motors. When the gyro sensor and acceleration sensor are fused, a complementary filter is designed to ignore the vibrations generated by the motors and to complement the drawbacks. As a result , we obtain accurate results than using each sensor. Also, it is possible to obtain a low delay results in robust to vibration than the low-pass filter or moving average filter, which is generally used for quadcopter. And we improved D controller, which have being used for attitude control of quadcopter, to quadcopter using gyro sensor. it was confirmed that the attitude is stabilized and error is reduced By using gyro sensor output instead of variation of estimated angle in D control.

Keywords: sensor fusion, noise attenuation, quadcopter, posture stabilization, PID control.

1 Introduction

In recent years, researchers have actively conducted a research on the autonomous unmanned systems. Among them, unmanned aircraft sector has many uses to perform a specific task or record images by freely exploring the area which is not easily accessible to humans [1], [5]. Compared to a helicopter, the typical vertical takeoff and landing aircraft, quadcopter has a more simple structure and boasts its advantage of easy control as its mathematical model is also relatively simple. For this reason many related researches have been carried out [5], [6].

As an actuator for rotating the four fixed-wings of the quadcopter, BLDC motor is used, but the vibration caused by using this motor has a significant impact on the acceleration sensor and gyro sensor. To ignore this vibration, a moving average filter or a low-pass filter is used in terms of software, but they pose a disadvantage of greater delay effects due to higher Smooth performance. Meanwhile, filters with much computational complexity such as a Kalman filter or a particle filter have its disadvantage in that real-time attitude estimation is difficult in low-end processing devices [5]. Therefore, there is a need to devise a sensor fusion method that can

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provide a characteristic of the vibration reduction and compensate the disadvantage of each sensor at the same time by complementing the strengths and weaknesses of the two sensors, so as to improve the characteristics of the sensor vibrations caused by the motor vibrations [2], [4].

In addition, PID control technique is mainly used in the attitude control of the quadcopter, wherein it is common for D control component to use the amount of change between the estimated attitude angle and the targeted attitude angle [3]. However, since the result of suing the two sensors is used for the estimated attitude angle, the result may contain some errors of the acceleration sensor, leading to a failure to accurately reflect changes in error. Therefore, to address this problem, the paper sought to achieve a more advanced effect by using the angular velocity obtained from the gyro sensor that can be more exact instead of the amount of change in the estimated angle when reflecting the amount of change in attitude.

The experimental result showed that the estimated value of attitude obtained through the sensor fusion method proposed in this paper helped to complement disadvantages of acceleration sensor and gyro sensor and promote strong resistance to motor vibrations, and the application of the improved PID control proposed based on the result contributed to improving the attitude control performance of the quadcopter.

2 Fusion of Acceleration Sensor and Gyro Sensor

An acceleration sensor is vulnerable against translation and vibration but does not accumulate errors, while a gyro sensor accumulates errors but is not easily affected by translation and vibration. Since both sensors measure physical values and their characteristics complement each other, weaknesses of the two sensors can be overcome through convergence. This study proposes mutually complementary convergence between the characteristics of each sensor through complementary filter. Equation (1) shows the known complementary filter Equation [1], [4].

$$\theta_f = \frac{1}{s}\left[\dot{\theta}_g - \left(K_p + \frac{1}{s}K_i\right)\left(\theta_{f_{pre}} - \theta_a\right)\right] \qquad (1)$$

In equation (1), θ_f represents the current estimated angle, $\dot{\theta}_g$ the angular velocity of the gyro sensor, θ_a the angle of the acceleration sensor, and $\theta_{f_{pre}}$ is the previously estimated angle. Rearranging Equation (1) by defining the difference between acceleration sensor and the estimated angle $(\theta_{f_{pre}} - \theta_a)$ as$\dot{\theta}_{err}$ results in Equation (2). And the differentiation of each side of Equation (2) results in Equation (3). Since$s \cdot \theta_f$ is $\dot{\theta}_f$, we get Equation (4) through transposition.

$$\theta_f = \frac{1}{s}\left[\dot{\theta}_g - \left(\dot{\theta}_{err} \cdot K_p + \frac{1}{s}\dot{\theta}_{err} \cdot K_i\right)\right] \qquad (2)$$

$$s \cdot \theta_f = \dot{\theta}_g - \left(\dot{\theta}_{err} \cdot K_p + \frac{1}{s}\dot{\theta}_{err} \cdot K_i\right) \qquad (3)$$

$$\dot{\theta}_g - \dot{\theta}_f = \dot{\theta}_{err} \cdot K_p + \frac{1}{s}\dot{\theta}_{err} \cdot K_i \qquad (4)$$

The right side of Equation (4) represents a regular PI control Equation. The control volume $\dot{\theta}_g - \dot{\theta}_f$ is calculated using $\dot{\theta}_{err}$ as the error value. Since the system shows no error in its normal state, 0 or a very small value is used for K_i. However, in case the size of K_p is too large, it reflects even the error of θ_a. Therefore, a small value which is just enough to resolve accumulated errors of θ_g is used instead. The block diagram expression of Equation (2) is as shown in Figure 1 below.

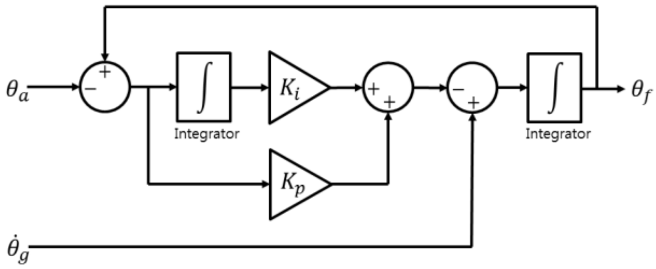


Fig.1. Block diagram of the proposed complementary filter

3 Improved PID Control

General attitude PID control of Quadcopter is performed with roll, pitch and yaw values acquired through convergence between the acceleration sensor and the gyro sensor [3], where D control refers to differential control using variation of angular error. Roll and pitch values acquired through convergence of two sensors are expressed in angles: when controlled towards 0 degree, angle variation is used for D control, where angle variation is equal to the angular velocity output from the gyro sensor. Therefore, stabilization can be achieved by using angle velocity measured by the gyro sensor for D control without need to use the amount of change in the estimated angle in which the error of the acceleration sensor is partly reflected in the control.

Figure 2 shows D control volume of the PID controller. Original D is the D control volume when controlling with θ_f, the result through the complementary filter.

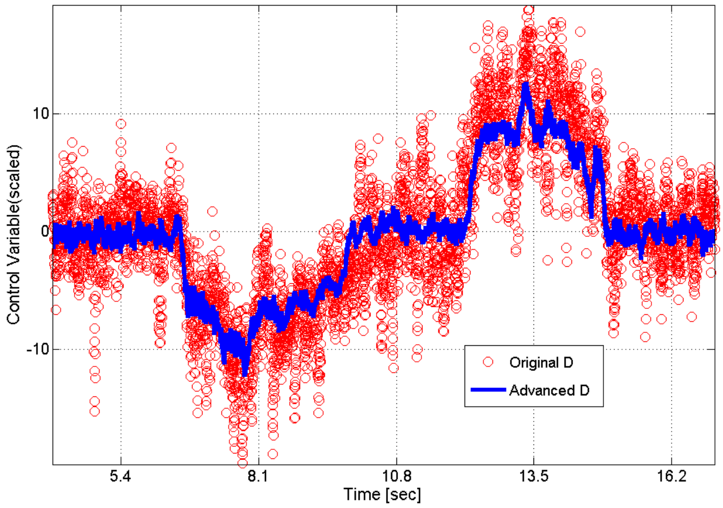


Fig. 2. Comparison of D component between conventiaonl method and proposed one

Advanced D is the control volume when performing D control only with the angular velocity [degree/sec] of the gyro sensor. The Figure shows that the control volume of Advanced D has less error than the control volume of Original D, which includes a portion of the acceleration sensor errors. Figure 3 shows the PID control block diagram applied with the improved D controller.

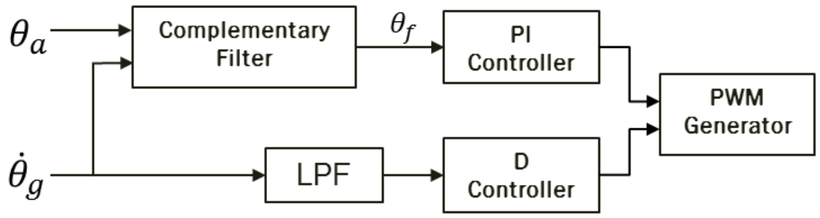


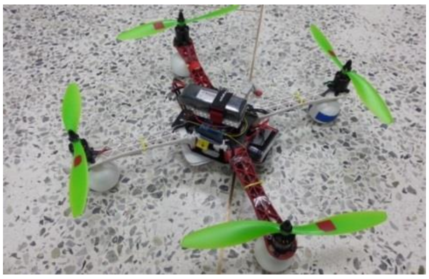
Fig. 3. PID controller with improved D controller applied

The value of acceleration sensor angle (θ_a) and gyro sensor angular velocity ($\dot{\theta}_g$) applied with the complementary filter is used as feedback for the PI controller, and, $\dot{\theta}_g$is used as feedback for D controller after going through a simple Smooth filter. Since$\dot{\theta}_g$ is angular velocity, it should be controlled towards 0 to maintain stable attitude.

4 Experiment and Results

An experiment was performed using an actual quadcopter to verify the performance of the complementary filter and the improved D controller. The 4 motors were operated for experiments requiring motor vibration. Figure 4 shows the quadcopter used for the experiment.

Figure 5 is the graph showing the result of the complementary filter after operating the motor. The parameter values of the complementary filter are identical to results of the experiment where the motor was not operated. The angle values of the acceleration sensor were scaled for graph expression, due to too much disturbances. Despite vibration of the acceleration sensor due to motor operation and drift of the gyro sensor, the result of the complementary filter passes between the values measured by the acceleration sensor.



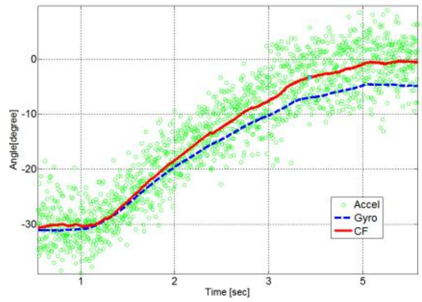


Fig. 4. Quadcopter used in the experiment (Right)

Fig. 5. Comparsion results of complementary filter (Left)

The experiment on quadcopter stability using the advanced D control was conducted by fixing all the other factors than D controller. Figure 6 show the angle variation graph for the roll axis and the pitch axis over time. The graphs show that the advanced D control produces more stable attitude than the original D control.

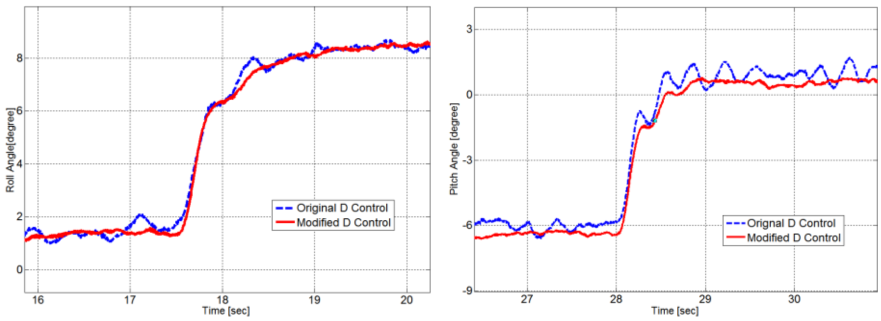


Fig. 6. Control stability comparisonof the improved PID conroller: (left)roll axis, (right)pitch axis

5 Conclusion

The results of this paper showed that the attitude of quadcopter can be stably controlled by solving the problems of the vibration occurring in the acceleration sensor and the drift and cumulative error of the gyro sensor, and applying the improved PID controller. It was also confirmed that the sensor noise-reduction sensor proposed in this paper can estimate the attitude in real time even in low-end processing devices that can be installed in the quadcopter and provide more fast. In addition, since the weights of the acceleration sensor and gyro sensor can be reflected by adjusting the gain value inside the filter, it is possible to apply by adjusting the gain according to the system to be applied. Also, the experimental results showed that the application of the improvement method for PID control technique that is commonly used in the attitude control of quadcompter can contribute to stable control of attitude by reducing unwanted vibrations that occur in the attitude control of the quadcopter. For future work, a further study on the attitude control of quadcopter and stabilization will be conducted based on the attitude values obtained stably. .

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